EVENT-RELATED BRAIN POTENTIAL STUDIES OF LANGUAGE

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INTRODUCTION

As cognitive neuroscientists, we do our research not only in the hopes of answering a specific question, but also in an effort to make a significant contribution to our understanding of consciousness. This is a road we choose despite the fact that we cannot provide the dictionary with a definition of consciousness. We believe that conscious cognition is inextricably related to the capacity for linguistic analysis. Insofar as this proposed relationship between consciousness and language exists, studying the mechanism of language will provide some valuable information on consciousness. Even if we are assuming too strong a relationship between consciousness and language, the link between some aspects of language and some aspects of conscious cognition guarantees that the study of one will lead to a gain of knowledge about the other.

However, simply investigating language is not an easy task in and of itself. In a review issue of *Cognition* devoted to theoretical and methodological issues in the study of human cognition, Swinney (1981) wrote, "language, like other cognitive functions, is a (dynamic) process. It is, in fact, precisely because it is a process that gaining an understanding of its nature has proved so intractable over the years; such an enterprise requires that we rely on more than just an examina-

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tion of the end-state characteristics of the process (such as memory representations) or static models of its putative underlying structure. Rather, if we are to achieve any substantive understanding of language performance it is necessary that we examine the microstructure of the entire process as it occurs in real time" (p. 307). Just a few paragraphs later, Swinney warns that "the characterizations we give to both whatever relevant informational types exist, and to the procedures by which these function, are intimately tied to assumptions about the techniques by which we examine these processes. There is simply no passive window which allows examination of mental processes without affecting those processes to some extent. . . . Given that the problems we face are to be best resolved by empirical examination of the real-time characteristics of language processing, we are in need of experimental techniques which are sufficiently flexible to examine such processing on-line and, simultaneously, which are as non-intrusive into the process under study as possible" (Swinney, 1981, pp. 308–309).

The event-related brain potentials (ERPs) recorded during language processes seem to fulfill Swinney's criteria. They allow a real-time examination of at least some of the brain proceses that underly language, cognition, and consciousness. And, as a measure, the ERP is relatively unobtrusive.

The present review of language and ERPs will detail the utility of the ERP as an unobtrusive, dynamic measure of certain psychological/brain processes engaged during language. Reviews of the ERPs and language literature in the past have read more like a discouraging survey of methodological woes and ERP inadequacies, with only a smidgen of optimism for the use of the ERP technique for language processing (Donchin, McCarthy, & Kutas, 1977; Friedman et al., 1975a; Galambos, Benson, Smith, Schulman-Galambos, & Osier, 1975; Hillyard & Woods, 1979; Molfese, 1983). The greater optimism of the current review reflects the shift of emphasis in this field away from the search for signs of hemispheric specialization, toward the use of ERPs to learn more about the processes/mechanisms presumed to support language processing and comprehension.

One possible explanation for this shift in experimental strategies may have been the seeming failure of the former tack in revealing large, consistent asymmetries that could be interpreted in light of the reported functional differences between the cerebral hemispheres. Although an occasional reviewer may have suggested that a bilateral or slightly asymmetric ERP component indicated the actual involvement of both hemispheres in the "supposedly" left hemisphere task under investigation, such results were more often viewed as problematic for the ERP methodology. For example, Galambos et al. (1975) concluded: "If one credits, as we do, the overwhelming clinical and behavioral evidence for hemispheric asymmetry during processing of speech signals, it is not unreasonable to expect a corresponding lack of symmetry in electrophysiological measures of hemispheric responsivity. The interhemispheric electrophysiological differences reported to date, however, are so tiny as to be barely believable. Hence, either the evoked response method is virtually blind to the crucial events we believe must be there, or the hemispheric differences are barely present in the conditions under which the measurements are currently being made" (p. 282).

In some cases, depth recordings within monkeys and humans have indicated that volume conduction can cause a unilaterally generated component to appear in scalp recordings over both hemispheres and, therefore, to seem less asymmetric than is really the case (Arezzo, Vaughan, & Koss, 1977; Barrett, Blumhardt, Halliday, Halliday, & Kriss, 1976). However, it has also become clear from cerebral blood flow and PET scan measures that many language functions can and do involve engagement of both cerebral hemispheres (Ingvar, 1983; Larsen, Skinhoj, & Lassen, 1978). Thus, the past observation of certain language-related ERP components over both hemispheres may have been rightful indications of bilateral activity.

The current review should dispel the notion of the ERP as insensitive to important language-related transactions within the brain. One of the beneficial side effects of the current approach to language and ERPs has been the discovery of several highly consistent asymmetries in ERP components elicited by individual words during reading (Kutas & Hillyard, 1982; Neville, 1980; Neville, Kutas, & Schmidt, 1982a, 1982b; Rugg, 1983a, 1983b, 1984b; Van Strien & Bouma, 1985). We will not focus on these findings of asymmetries in this review: rather, this chapter will focus on some of the recent advances in the field by detailing what we have learned about semantics and language from ERP research and what we have learned about ERPs by using pictorial and linguistic stimuli.

APPROACHES TO COGNITIVE ERPS

Before beginning the review, it will be instructive to examine the different ways that ERP measures are used to illuminate mechanisms in information processing since, at present, there are no firm data on the neurophysiological substrate of *any* endogenous, "cognitive" ERP component. One approach has been to adopt a working model of a specific cognitive process and to use ERP measures obtained in parallel with the engagement of that process as a test of the model. This approach presupposes that the ERP measure has been validated; that is, that the essence of the particular cognitive process is reflected in the chosen ERP measure (i.e., component). Insofar as the cognitive process and its manifestation in an ERP measure can be delineated precisely, predictions can be made about systematic variations in the ERP measure (be it amplitude, latency, or scalp distribution). In so doing, the accuracy of the descriptions of the cognitive processes assumed to underly the behavior in question can be assessed and modified as necessary. The goal of this approach is a more precise definition of the cognitive process, which in turn can help in fine tuning or reducing the number of viable, alternative theories of the cognitive process under study (see also Hillyard & Kutas, 1983).

The other main approach to cognitive ERPs is atheoretic. A psychological variable is systematically manipulated, the electroencephalogram (EEG) is recorded, and the resultant ERPs are described. This approach is undertaken whether or not the investigator has the slightest inkling of the ERP concomitants of the cognitive process. Generally, this has not been an unreasonable approach. While not all brain or cognitive processes are associated with an ERP signature at the scalp, there is, at present, no formula for determining which processes will and which will not. The success of this latter approach is evidenced by the increasingly long list of psychological processes that do have ERP signatures, and in the progress that has been made using these ERP components to test current-day perceptual and cognitive theories.

However, as any researcher has experienced, the best-laid experimental plans can and do go awry. On occasion, the experimentally sound route of testing a specific hypothesis about a cognitive process is diverted into a "fishing" expedition because the anticipated ERP componentry is not obtained. Such an experimental detour, however, may not be so bad if the outcome is the first step towards bestowing validity upon an ERP parameter as a measure of some inferred cognitive process (Kutas, 1983). A case in point is the experimental work on language and the N400 component.

P300 AND N400 IN COGNITIVE STUDIES

Conditions Known to Elicit the P300

Since its discovery in the early sixties, there have been numerous investigations of the P300 during different cognitive tasks. While there is no consensus as to the specific cognitive process manifested by the P300, the antecedent conditions for its elicitation, as well as those for varying its amplitude and latency, have been well-documented (for reviews see Donchin, 1981; Donchin, Ritter, & McCallum, 1978; Johnson, this volume; Pritchard, 1981). Almost any element of surprise within an experimental setting is guaranteed to elicit a P300 component. An unexpected deviation (i.e., change) in a stream of events, particularly when attended, results in a large positive wave over the central and parietal scalp called the P300. It has been found to be relatively independent of the modality of the eliciting stimulus (Simson, Vaughan, & Ritter, 1977; Snyder, Hillyard, & Galambos, 1980). Thus, either a red light among a series of blue lights, or a high-pitched tone occurring unpredictably within a sequence of low-pitched tones, yields remarkably similar P300 waves.

While a binary decision between two equiprobable events is sufficient to elicit a P300, its amplitude is particularly sensitive to fluctuations in probability. For example, increasing the proportion of randomly occurring deviations within a

Bernoulli sequence has been shown to yield P300s of linearly decreasing amplitude (Duncan-Johnson & Donchin, 1977). Indeed, one of the more influential views of the P300 component, the expectancy model, is based on the relation between P300 amplitude and subjective probability (Squires, Wickens, Squires, & Donchin, 1976).

Like its amplitude, the latency of the P300 has been found to be highly but systematically variable. In fact, the lability of P300 latency, which can vary from 300 to 1000-plus milliseconds, led many investigators either to use P300 as a generic term or to replace it with the term *late positive complex* (LPC). The more complex the stimulus evaluation phase of the decision process leading to the P300, the longer its measured peak latency (Donchin, Ritter, & McCallum, 1978; Kutas, McCarthy, & Donchin, 1977; Ritter, Simson, & Vaughan, 1972).

ERPs to Semantically Incongruous Sentences

Given the above data base, Kutas and Hillyard, in 1978, decided to use the P300 component of the ERP as a marker of semantic deviance. They hoped to use variations in P300 latency to index the effect of contextual constraint on the speed of word recognition and comprehension processes. The study was designed to take advantage of our knowledge of the P300 to gain better understanding of the role of context in sentence processing. The feasibility of this approach was attested to by Friedman's studies of the P300, sentence processing, and syntactic closure (Friedman, Simson, Ritter, & Rapin, 1975b).

Kutas and Hillyard anticipated that unpredictable sentence endings would yield a sizeable P300 component if they were embedded in a series of meaningful sentences. They planned to use the latency of the P300 to examine the role of varying degrees of contextual (i.e., sentential) constraint on the speed of word processing. To this end, the sentences for the study included nursery rhymes (e.g., "Little Miss Muffet sat on a tuffet."), clichés (e.g., " 'Tis easier to give than to receive."), and factual statements (e.g., "The largest city in England is London.") for which the terminal words were highly constrained. In addition, some less constrained sentence fragments for which several meaningful endings were possible (e.g., "The two suspects were arrested for murder.") were used. However, before embarking upon a full-blown study wherein each of the sentence types was ended by highly probable and less probable endings, Kutas and Hillyard (1980a) implemented a simpler design including less probable endings only at the ends of sentences of medium contextual constraint.

Subjects were presented (by slide projector) with 160 different seven-word sentences, one word every 700 ms. They were asked to read the sentences in order to complete a questionnaire subsequent to the recording session. The majority of the sentences (three-fourths) ended meaningfully and as expected. The remaining one-fourth of the sentences were terminated by an unexpected word (e.g., "He shaved off his mustache and eyebrows."; "He listed his occupation as a hasbeen."; "I take coffee with cream and milk."). The final word of each sentence was punctuated by a period, so that subjects were aware of the end of the sentence.

Expected sentence completions were associated with a late positivity in the region 300 to 600 ms poststimulus. In contrast, unexpected endings seemed to be characterized by a negative component with a centro-parietal maximum (N400) in the same time range. The lack of a P300 to incongruous endings was surprising; therefore, Kutas and Hillyard attempted a replication. They presented a new group of subjects with the same set of sentences with one modification. The unexpected words from the previous study were replaced by semantically anomalous words (e.g., "He shaved off his mustache and city."; "He listed his occupation as a chocolate."; "I take my coffee with cream and dog.").

As in the previous experiment, infrequently occurring semantic anomalies did not elicit a P300 component, but rather a large N400 component (see Figure 1). It was clear from these data that the N400 was more than the absence of a P300, but a component in its own right that was substantially negative relative to the pre-terminal-word baseline. While there was a positivity following the N400 in these two studies, its amplitude was no larger following incongruous/anomalous than congruous endings.

Like the P300, the N400 has proven to be an extremely robust component. It is readily evoked by semantic anomalies in the visual and auditory modalities (Holcomb, 1985; McCallum, Farmer, & Pocock, 1984). Within the visual modality, it matters little whether the eliciting signal is an English, French (Besson & Macar, 1987), or Spanish (Kutas, 1985b) word, or an American Sign Language gesture (Kutas, Neville, & Holcomb, 1987; Neville, 1985). Terminal word exposure durations from 40 to 250 ms yield the same incongruity effect.

ALTERNATIVE VIEWS OF THE N400

From one perspective, both the P300 and the N400 components can be characterized as responses to deviance. At issue, however, is what it is about the stimulus or the task parameters that determines whether a deviant stimulus will evoke an N400, a P300, or both. Several classifications of the situations yielding N400s rather than P300s suggest themselves:

1. The N400 reflects deviation within a system of symbols, while the P300 reflects deviation relative to physical parameters (e.g., a high pitched tone within a sequence of low tones).
2. The N400 follows the violation of expectancies derived from one's long-term memory store, such as the knowledge of language and the expectancy that a series of words will make sense. The P300, in contrast, follows

the violation of short-term expectancies, such as those formed across an experimental session.

3. The N400 component is specific to language, or some aspect of language processing, while the P300 is a more general reaction to surprising or task-relevant events, both within and outside the domain of language.

The following review examines the experimental results bearing on these alternative, although not exclusive, positions.

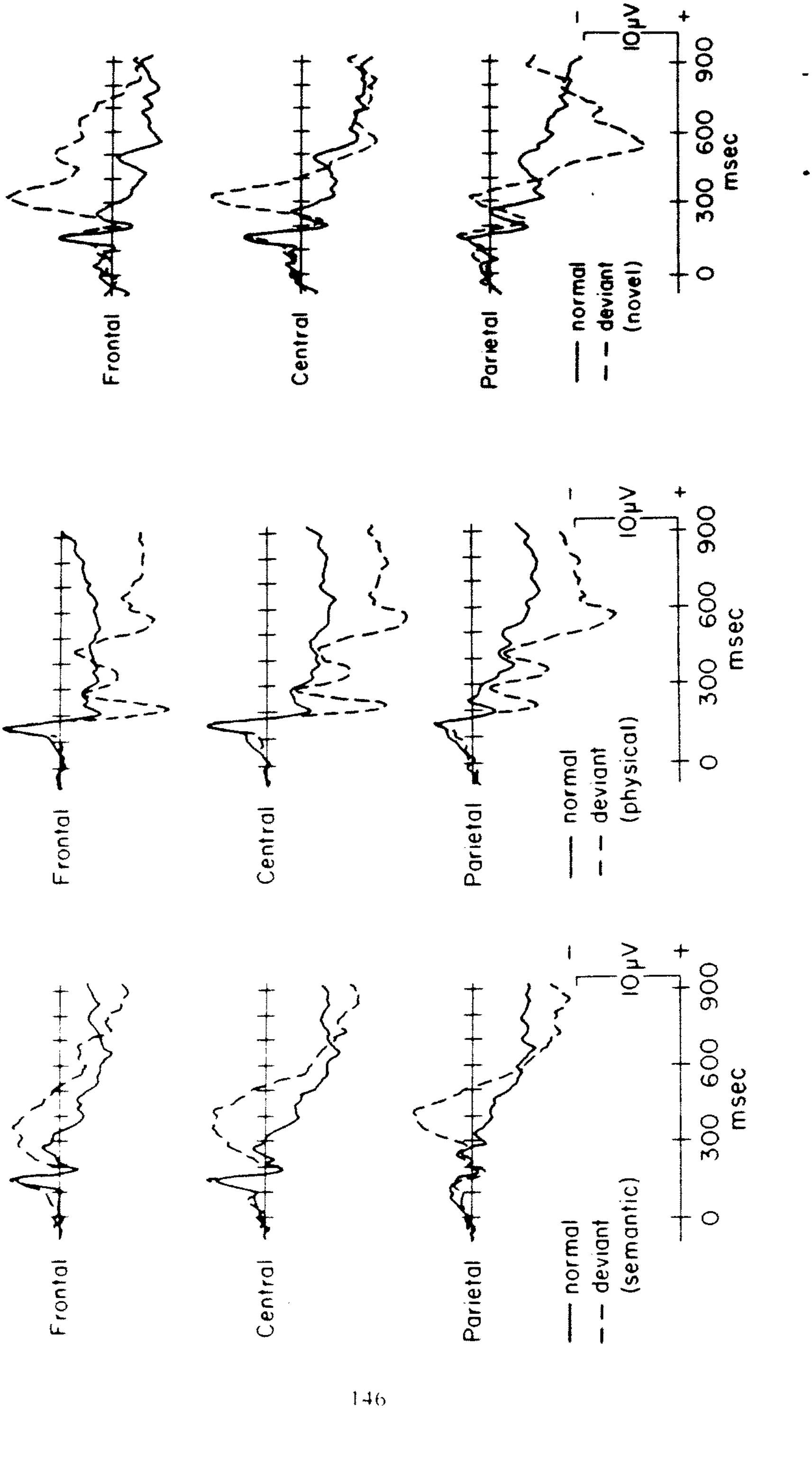
The N400 and Deviation

Nonlinguistic Deviations Within a Linguistic Context

Kutas and Hillyard's first description of the N400 (1980a) was derived from three experiments with different types of deviant sentence completions, namely, moderate and strong semantic deviations, and physical deviations. At issue was whether any or all deviations within a sentence context would result in an N400, or whether some might, instead, be followed by a P300 wave. The physical deviations took the form of meaningful terminal words presented in larger type than the preceding words (e.g., "She put on her high heel SHOES."). Unlike the N400 component elicited by semantic anomalies, such physical deviation resulted in a complex of late positive waves. Thus, violations within sentences did not invariably lead to N400 waves.

In a separate experiment along these same lines, Kutas & Hillyard (1980c) utilized terminal words which were either physically deviant, semantically deviant, or both (e.g., "I take coffee with cream and ENGINE."). The responses to these dual deviations seemed to be comprised of a late negative and a late positive wave. Algebraic recombination of the waveforms produced by physical and semantic deviations alone proved to be statistically indistinguishable in the 300 to 600 ms latency range from the waveform produced by the dual deviation. These results were taken as evidence that the N400 and P300 are independent components which can be elicited simultaneously by a single word. This finding is consistent with the view that, at least in some cases, the physical and semantic dimensions of a word are processed in parallel and noninteractively.

In another study, Kutas and Hillyard (1984c) tested the generality of their finding of late positive waves in response to physical incongruities. Accordingly, they terminated one quarter of their sentences with complex, unrecognizable abstract drawings, and the remainder with semantically appropriate words. Courchesne, Hillyard, and Galambos (1975) had reported that the infrequent occurrence of such abstract slides in a random series of "2's" and "4's" resulted in a frontally-distributed P300 preceded by an N200. The ERP responses to the novel slides, unexpectedly large words, and semantically anomalous words in the Kutas and Hillyard (1984c) study can be compared in Figure 1.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Novel slides at the ends of sentences elicited a large fronto-central negativity peaking at 320 ms. This negative component had a significantly more anterior distribution and shorter latency than the N400 produced by semantically anomalous completions of these same sentences. In addition, this N320 was accompanied by a large positive wave peaking at 530 ms over the parietal area. In short, the ERP produced by unrecognizable drawings during a reading task more closely resembled the N200–P300 complex elicited by these same stimuli in a different context than it resembled the N400 response following semantic anomalies.

Deviations Within a Nonlinguistic Context

The experiments just described tested the specificity of the N400 response by presenting nonlinguistic deviations within a linguistic context. A complementary approach to defining the type of deviation that will, or will not, evoke this component is to present anomalies within symbolic or meaningful contexts other than language.

Besson and Macar (1987) compared the brain's response under four different experimental conditions, each of which contained predictable and unpredictable terminations to sequences of stimuli. The conditions were: (a) visually presented sentences, (b) well known French melodies, (c) geometric figures ordered in increasing size, and (d) the notes of the musical scale in ascending order. In each condition one quarter of the stimulus trains ended incongruously, that is, with a semantically anomalous word, an inappropirate note, a geometric figure smaller than the one preceding, or a musical note of pitch lower than the one preceding, respectively. Only one type of incongruity yielded an N400 relative to its congruent control: semantically anomalous words at the ends of sentences. The other three classes of incongruous stimuli produced late positivities of the P300 variety.

To date, the N400 response to a deviation within a sequence of stimuli has been obtained only if the context and the deviation are linguistic. Yet, few ERP experiments have utilized stimuli which are meaningful or over-learned but nonlinguistic in character. Besson and Macar (1987) demonstrated that a single misplaced note within a familiar song did not yield an N400, but many other types of musical ''incongruities'' are no doubt possible. For the naive layperson, a well-known piece of music forms a coherent whole in which one passage sets

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Figure 1. Column 1 shows the comparison of the grand average ERPs (across all subjects) to the normal, semantically congruent final words and to the semantically anomalous words. Columns 2 and 3 show grand average waveforms to physically deviant words and to novel slides, respectively. (From Kutas & Hillyard, 1984c. Copyright 1984 by the New York Academy of Sciences. Reprinted with permission.)

up an expectation for the next. For a trained musician, there may well be rules of composition and expected patterns or sequences, even within a new piece of music. The ERP concomitants of music perception deserve further attention. Moreover, an internally consistent, complex system of symbols and of rules for combining them also exists in mathematics, yet the possible similarities between mathematical and linguistic modes of thought is a topic which has been virtually untapped in ERP research. Both music and mathematics deserve further consideration before we can unequivocally conclude that the N400 is restricted to violations within a linguistic context.

The N400 and Mental Rotation

There has been one report of an N400-like component recorded following a stimulus which was neither deviant nor linguistic. Stuss, Sarazin, Leech, and Picton (1983) required subjects to perform a mental rotation in order to decide if two complex geometrical figures were identical or mirror images. The ERPs recorded to these visual stimuli were characterized by a prominent negativity peaking at 421 ms. This negative component, *Ny*, did not vary as a function of whether the subjects responded "same" or "different," but rather appeared to be elicited by the task of mental rotation per se. The authors reported that Ny was observed in word reading and picture naming conditions as well.

The ERPs recorded during mental rotation and naming are shown in Figure 2. The average waveforms obtained during the reading task were not presented for comparison, although the authors reported that there were essentially no differences in the ERPs recorded across the three conditions. Note, however, that in the ERPs elicited during the mental rotation task, there was no clear Ny peak in the waveforms over posterior regions, but rather a broad negativity. The presence of a Ny component in the waveforms recorded from the back of the head was inferred from its presence over frontal regions.

Other aspects of Stuss et al.'s data are also somewhat puzzling. For example, pictorial stimuli (photographs, line drawings, and the like) generally elicit ERPs characterized by sizeable frontally-distributed negativities (Kutas, 1981; Kutas & Hillyard, 1984c; Neville, Snyder, Woods, & Galambos, 1982). The ERPs to words, on the other hand, do not seem to contain such large frontal negativities. However, Stuss et al. found no differences between the ERPs to words and pictures. One reason for this discrepancy may be that their word stimuli were appreciably larger than those generally used. It is possible that the previously observed ERP differences were due to differences in the physical characteristics of word and picture sitmuli, such as size. Future experiments using within-subject comparisons of ERPs to line drawings and words should help resolve this issue.

Stuss et al. noted that while their reading condition was essentially equivalent to that employed by Neville, Kutas, and Schmidt (1982a), their ERPs were not.

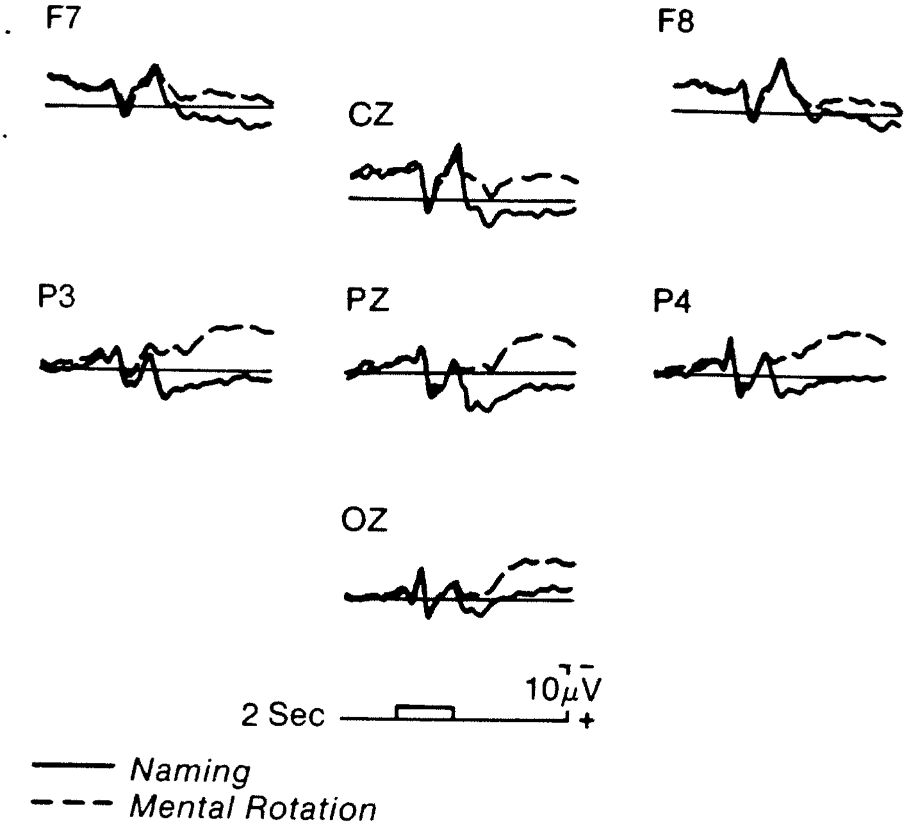

Figure 2. Comparison of naming and mental rotation conditions. This figure shows the grand mean waveform for the eight subjects who completed both experiments. Total recording epoch with 2 sec; the bar indicates stimulus presentation. (From Stuss, Sarazin, Leech, & Picton, 1983. Copyright 1983 by Elsevier Publishing Company. Reprinted by permission.)

Neville et al. found that words which subjects read and identified in writing elicited a series of asymmetric components. Among them was a frontally-distributed negativity (N410) that was greater over the left than the right hemisphere, regardless of the visual field in which the word was presented. While Stuss et al.'s Ny component did have a frontal maximum reminiscent of the N410, its lateral asymmetry was reversed, being more like that of the N400 (i.e., larger over the right than the left hemisphere). Stuss et al. suggested that the difference between the Ny and N410 in lateral asymmetry might be due to the differences in stimulus presentation: full-field horizontal in their case, versus half-field vertical in Neville et al.'s. However, this explanation seems unlikely, given that subsequent work from Neville's laboratory has revealed N410 components to full-field horizontal presentations of words (Neville, Kutas, Chesney, & Schmidt, 1986).

Although component Ny had the frontal distribution of the N410 rather than the posterior distribution of the N400, Stuss et al. finally resolved to equate the Ny with the N400 seen following semantic anomalies. They concluded that while the mental process associated with Ny/N400 might be active during semantic analysis, it certainly could not be unique to it. In conclusion, they suggested that the Ny/N400 reflected "some process required in the evaluation of any complex stimulus" (Stuss et al., 1983, p. 143). Recently, these authors have proposed that access to long-term memory is this process (Stuss, Picton, & Cerri, 1986). They have contrasted the N400 and P300 components of the ERP as follows: "The P300 may occur in response to a signal for which an interpretation is readily (although not immediately) available in short-term memory and the N400 may occur when the interpretation requires access to long-term memory." According to this framework, N400 amplitude is an index of the amount or extent of memory search.

It is impossible, at present, to determine unequivocally whether the negativities elicited during reading, naming, and mental rotation reflect one and the same process, and whether or not this process also leads to the N400 observed following semantic anomalies (see also Ritter et al., 1984). Intracranial recordings in humans performing such tasks may aid in this determination (McCarthy & Wood, 1984; Smith, Stapleton, & Halgren, 1986). In any case, Stuss et al. have put forth a clear and testable hypothesis for elicitation of the Ny/N400 component.

The N400 and Verbal Memory

Violations of Semantic Knowledge

Over the last few years a handful of investigators have used ERPs to study verbal memory (Johnson, Pfefferbaum, & Kopell, 1985; Karis, Fabiani, & Donchin, 1984; Paller, Kutas, & Mayes, 1987; Sanquist, Rohrbaugh, Syndulko, & Lindsley, 1980; Warren, 1980). A study of Neville, Kutas, Chesney, and Schmidt (1986) illustrates that both the realization of semantic incongruity and the activity of memory processes are reflected in the ERP, but that the different cognitive processes are evident in different components of the ERP. These investigators examined the ERPs to words following congruous and incongruous contexts and during a subsequent recognition test. Their subjects read four-word phrases and pressed one of two buttons to indicate whether or not the meaning of a fifth word fit with the sense of the preceding phrase. Shortly thereafter, the subjects were asked to identify the 'old' words (fifth word stimuli) during the presentation of a list which also contained 'new' words.

During the initial judgment task, 'no fit' words (e.g., "a type of weapon: *sheep*") elicited significantly larger N400s than did the 'fit' words (e.g., "a type of animal: *dog*"). However, these same ERPs, re-averaged on the basis of subsequent recognition, indicated that N400 amplitude was not predictive of memory performance. Rather, correct identification of both types of 'old' words was associated with the enhancement of a late positivity, which followed the N400 in the case of 'no fit' words. A number of other investigators have observed a similar relationship between the amplitude of a late positivity and memory for isolated words or pictures (Karis, Fabiani, & Donchin, 1984; Neville, Snyder, Woods, & Galambos, 1982; Paller, Kutas, & Mayes, 1987; Sanquist, Rohrbaugh, Syndulko, & Lindsley, 1980).

More pertinent to the proposed relationship between the N400 and the retrieval of information from memory were the ERPs recorded *during* the recognition test (see Figure 3). If the N400 response were solely a measure of the ease or difficulty of accessing or retrieving information from memory, then its amplitude should reflect the success or failure of recognition memory. It did not. Instead, it was the variation in the amplitude of a late positive component (P650) that

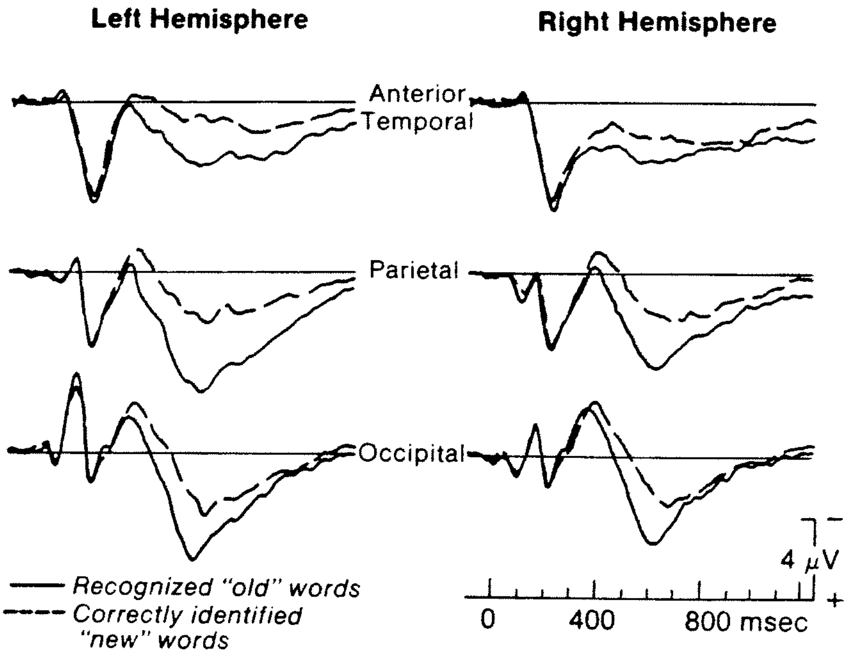

Figure 3. Grand average ERPs, recorded during the recognition task, for correctly recognized old ('fit' and 'no fit') words and new words. (Data from Neville, Kutas, Chesney, & Schmidt, 1986.)

distinguished the ERPs to correctly recognized old words, correctly identified new words, and forgotten old ones.

Both the ERPs to congruous endings in the judgment task and those collected during the recognition test contained negative peaks around 400 ms. Over the front of the head, this negativity was larger over the left than right hemisphere; over the back of the head this asymmetry was reversed. Both the timing and distribution of the anterior negativity were reminiscent of those reported for the N410 elicited by isolated words presented to the left and right visual fields for written identification (Neville, Kutas, & Schmidt, 1982a, 1982b). In contrast, the posterior negativity was a smaller version of the N400 following incongruous words. Thus, there seem to be at least two distinct negative components within the 300 to 500 ms latency range of the ERPs to words—the N400 and the N410. Without multiple recording sites these two negativities cannot be dissociated, and much energy can be expended needlessly in attempts to subsume findings with both negativities within one psychological construct.

In the foregoing experiment (Neville et al., 1986) it was possible to contrast the ERPs elicited by the same words following a sentence context and, subsequently, devoid of that context. Such a comparison showed that, even if they were correctly recognized, 'no fit' words did not yield an N400 when divorced from their original incongruous contexts. Neville et al. suggested that this result could be taken as evidence that successful recognition of isolated words does not require reconstruction of the encoding context. The validity of this interpretation relies on the generality of the N400 response to incongruity. It is equally plausible that the encoding context *was* reconstructed by the subjects, but that incongruity between a current stimulus and a phrase retrieved from episodic memory is not sufficient to elicit an N400.

In fact, the experiments reviewed thus far have not been conclusive as to whether the N400 follows violations dependent on episodic information, or is elicited exclusively by violations of the semantic knowledge common to our subject population. The sentences which led to N400s in Kutas and Hillyard's experiments required some familiarity with commonly-known facts, as well as a knowledge of the English language, for their incongruity to be appreciated. They did not require any personal experience with the topics of the sentences. For example, the sentence "Jack takes his coffee with cream and dog" is nonsensical because we know that coffee can be taken black, with cream, sugar, saccharin, or any number of sweeteners, but not dogs. However, its incongruity is evident whether or not the reader knows anyone named Jack.

It has been argued that word definitions and world knowledge constitute a memory store which is distinct from the episodic memory for events in one's personal experience (Tulving, 1972; Fodor, 1983). In fact, a semantically acceptable sentence can be incongruous only in light of one's personal experience. A semantically acceptable sentence such as "Jack takes his coffee with cream and sugar" would be anomalous if the reader happened to know that Jack was diabetic and never used sugar. Sentences such as this have been used in the recent work of Fischler and colleagues; the results indicate that the N400 response is not restricted to violations of semantic knowledge.

The N400 and Violations of Episodic Information

In a series of studies, Fischler et al. have compared ERPs elicited by incongruities based in semantic, episodic, and personal knowledge (Fischler, Bloom, Childers, Roucos, & Perry, 1983; Fischler, Childers, Achariyapaopan, & Perry, 1985; Fischler, Bloom, Childers, Arroyo, & Perry, 1984). In the first such study, subjects were asked to verify a set of simple semantic propositions (Fischler et al., 1983). The set was equally divided among true affirmatives (36), false affirmatives (36), true negatives (36), and false negatives (36), as in the following examples:

True affirmative:	"A robin is a bird."
False affirmative:	"A robin is a vehicle."
True negative:	"A robin is not a vehicle."
False negative:	"A robin is not a bird."

The final words of both false affirmative and true negative sentences elicited an N400 relative to the other two sentence types (see Figure 4). Thus, the ERP did not reflect the truth or falsity of the propositions, but rather the associative relationship between the two major lexical items (i.e., content words) of the sentence. Regardless of whether a sentence contained an "is" or an "is not," unrelated word pairs (e.g., ". . . robin . . . vehicle") elicited an N400 while related word pairs (e.g., ". . . robin . . . bird") did not. This result indicates that the N400 is less sensitive to the propositional content of a statement than to the strength of association between entires in the mental lexicon. The authors noted that in natural discourse there is substantial overlap between these two factors; "negative statements are typically used to deny a supposition that is reasonable (e.g., "a whale is not a fish") or to point out exceptions within a context (e.g., "Senator Smith isn't a man")" (Fischler et al., 1983, p. 408).

Fischler and colleagues have pursued the generality of this relationship between the N400 component and the strength of word associations. In particular, they have compared the ERPs to incongruities based on one's knowledge of English with those to incongruities based on other knowledge stores. Fischler et al. (1985) required subjects to memorize a set of statements of the form: "Diane is a chemist" and "Matthew is a lawyer." The names and occupations were then recombined to form a set of false statements (e.g., "Diane is a lawyer" and "Matthew is a chemist"). After training, the subjects were able to discriminate between true and false statements with 97% accuracy. On the following day, ERPs were recorded during four repetitions of the true and false statements. In separate blocks, subjects either made true/false judgments or read the statements

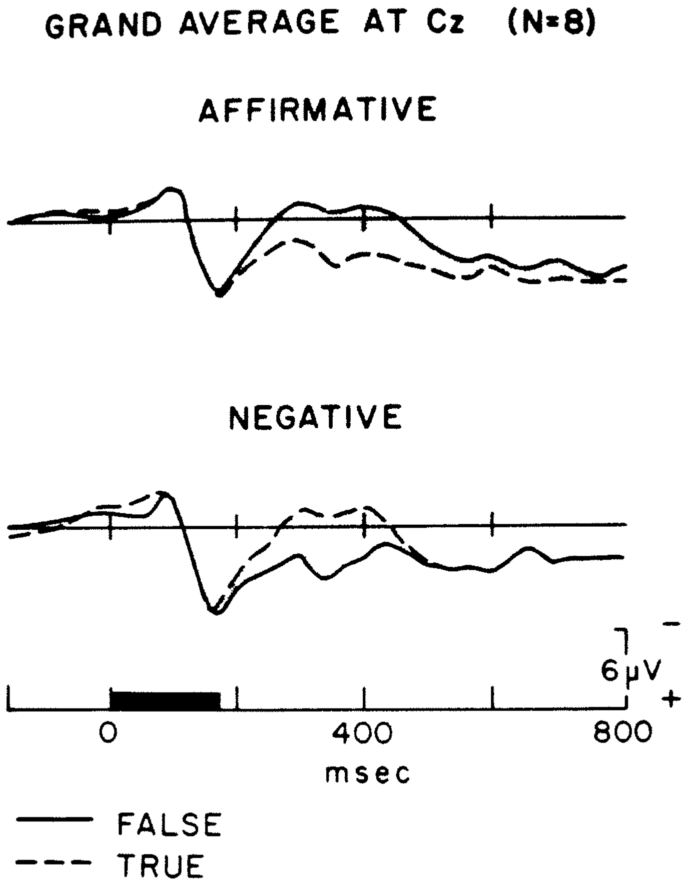

Figure 4. Grand average ERPs for true versus false sentences, electrode Cz. Onset of the final word of the sentence was at 0 ms. (From Fischler, Bloom, Childers, Roucos, & Perry, 1983. Copyright 1983 by the Society for Psychophysiological Research. Reprinted by permission.)

without making a behavioral response. The false statements elicited an N400 very similar to that reported by Fischler et al. (1983), despite the fact that the relationships between the names and occupations were arbitrary, having been formed the previous day (see Figure 5).

In a follow-up experiment, Fischler et al. (1984) recorded ERPs to true and false statements that were self-referential. True statements were culled from a questionnaire administered to each subject. These included "strong" statements such as "My name is Ira"; "I am male"; and 'weak' statements such as "My shoe size is eight"; "My favorite author is Tolstoy." False statements were

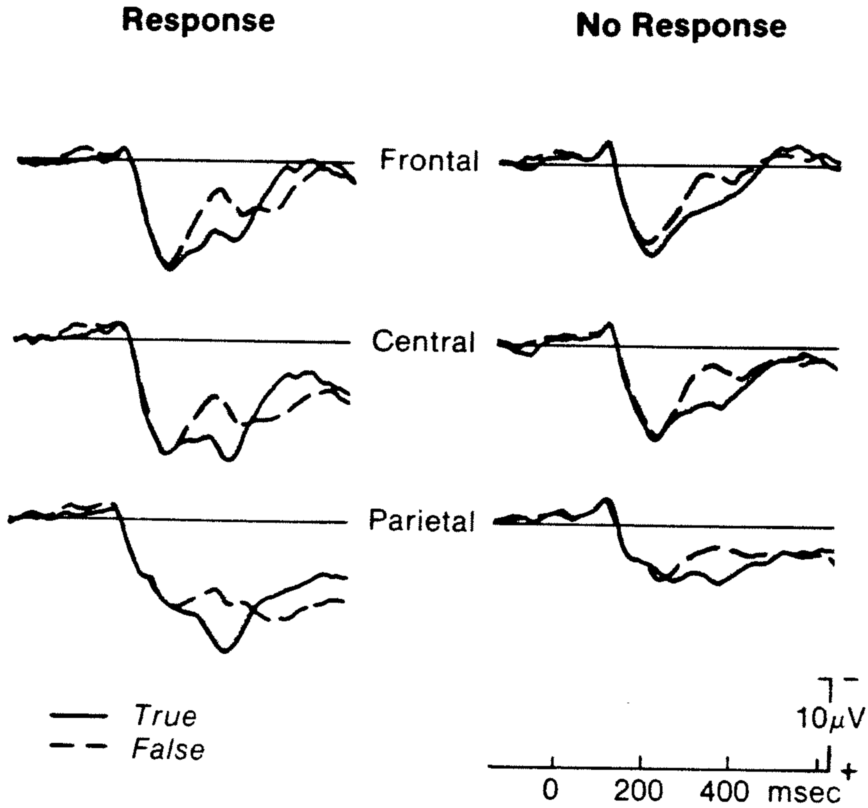

Figure 5. Grand average ERPs for true versus false statements during response (R) and no response (NR) trials. Onset of the final word of the sentence is at 0 ms. (From Fischler, Childers, Achariyapaopan, & Perry, 1985. Copyright 1985 by Elsevier Science Publishers B.V. Reprinted by permission.)

constructed by substituting a semantically acceptable word for each correct item on an individual basis (e.g., "My shoe size is eleven"). Both strong and weak false statements yielded an N400 relative to the response to true items (see Figure 6). The N400 was significantly larger in amplitude for the strong than the weak false statements.

Taken as a whole, Fischler's data clearly demonstrate that the N400 is not specific to semantic anomalies. Interpretable false statements can also yield N400s. More importantly, the results indicate that the N400 is sensitive to associations or relationships within semantic and episodic memory. Although these experiments utilized different subjects, a comparison of the N400s in Figures 4, 5, and 6 reveals no obvious amplitude or latency differences which

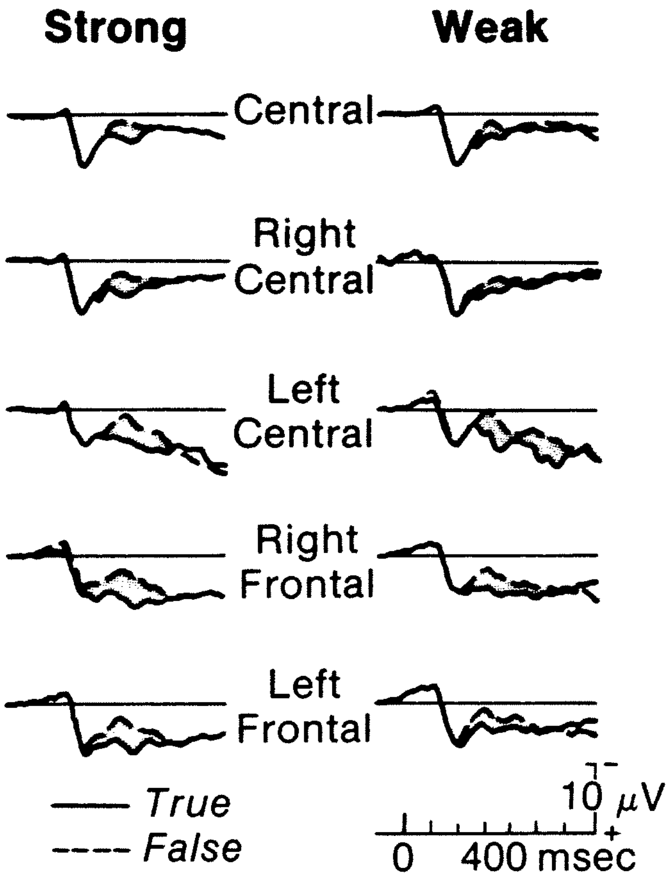

Figure 6. Grand average ERPs for true versus false statements. Onset of the final word of the sentence is at 0 ms. (From Fischler, Bloom, Childers, Arroyo, & Perry, 1984. Copyright 1984 by Pergamon Press. Reprinted by permission.)

correspond to the differences in age or type of information that had been contradicted by the false statements. Untrue statements, whether referring to over-learned information such as one's name, or to arbitrary relationships learned within the context of an experiment, elicit this ERP component as readily as sentences which would be incongruous to any speaker of English at any time. Finally, these results, as well as those of Neville et al. (1986), indicate that a view of the N400 as a unique signature of memory encoding or retrieval processes in untenable. While the N400 is sensitive to processes which require memory, such as the comprehension of language, its elicitation does not seem to be specific to the activity of memory processes per se.

The N400 and Language

Grammatical Deviation

Given that the N400 seems to show some specificity to language processing, further studies have attempted to delineate the type of linguistic deviations that will elicit this component, and to define its relation to psycholinguistic constructs. Kutas and Hillyard (1983) presented subjects with prose passages containing both semantic and grammatical anomalies. The semantic anomalies consisted of inappropriate words placed either at the ends (e.g., "Turtles are smarter than most reptiles but not as smart as mammals such as dogs or *socks*.") or at intermediate positions within sentences (e.g., "Other well-known reptiles are snakes, lizards, *eyeballs* and alligators."). Grammatical incongruities consisted of errors in verb tense (e.g., "Ice begins to *grew* around invisible specks that always float in the air.") or the incorrect use of a singular or plural noun or verb (e.g., "As a turtle grows its shell *grow* too."). Subjects read the passages silently in order to answer multiple-choice questions. They were told that the text would contain a number of errors but that these would not be included among the questions.

Semantic deviations produced nearly identical late negativities regardless of their position within the sentence, although the sentence intermediate N400s were not superimposed upon the slow positive shift typically seen at the ends of sentences (see Figure 7). The presence of an N400 response to both intermediate and terminal anomalies is in accord with the hypothesis that successive words are integrated with the preceding context on a moment-to-moment basis (Carpenter & Daneman, 1981; Just & Carpenter, 1980; Marslen-Wilson, Tyler, & Seidenberg, 1978; Tyler & Marslen-Wilson, 1977), rather than being held in a buffer until the end of a sentence.

The grammatical errors, in contrast to semantic anomalies, did not produce N400s (see Figure 8). When compared with grammatically and semantically appropriate control words occurring in comparable sentence positions, grammatical deviations did elicit some additional negativity in a 300–400 ms latency window, but this was small and clearly visible only at frontal sites.

It is unlikely that these grammatical errors were as noticeably "deviant' or disruptive of ongoing sentence comprehension as were the semantically anomalous words. While the construction of stimulus materials with more blatant syntactic deviations—but without semantic anomalies—may prove difficult, future ERP research should be aimed at teasing apart these different levels of language processing. In the meantime, we can tentatively identify the N400 component with semantic processes.

Word Expectancy

Several experiments have been aimed at determining which aspect of semantic analysis is reflected by the N400 component. Kutas and Hillyard (1984b) exam-

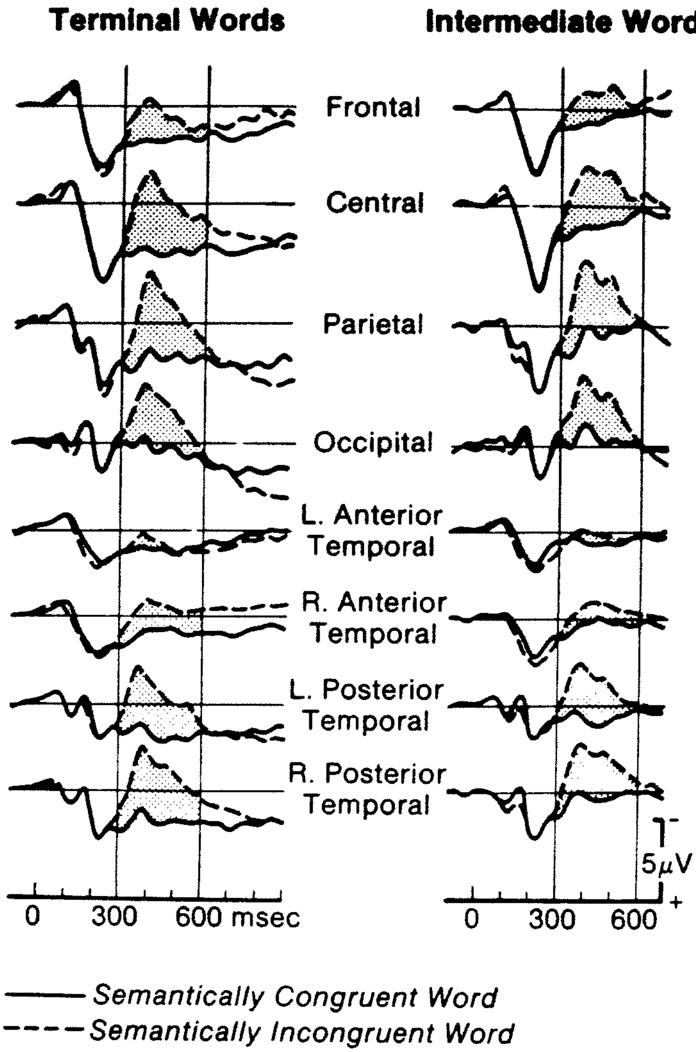

Figure 7. Grand average ERPs to semantically anomalous words at intermediate and terminal positions of sentences (dashed lines). The superimposed waveforms (solid lines) are ERPs to semantically congruent words at corresponding positions. Content words that immediately preceded the intermediate semantic anomalies were chosen as the congruous words for these comparisons. (From Kutas & Hillyard, 1983. Copyright 1983 by the Psychonomic Society. Reprinted by Permission.)

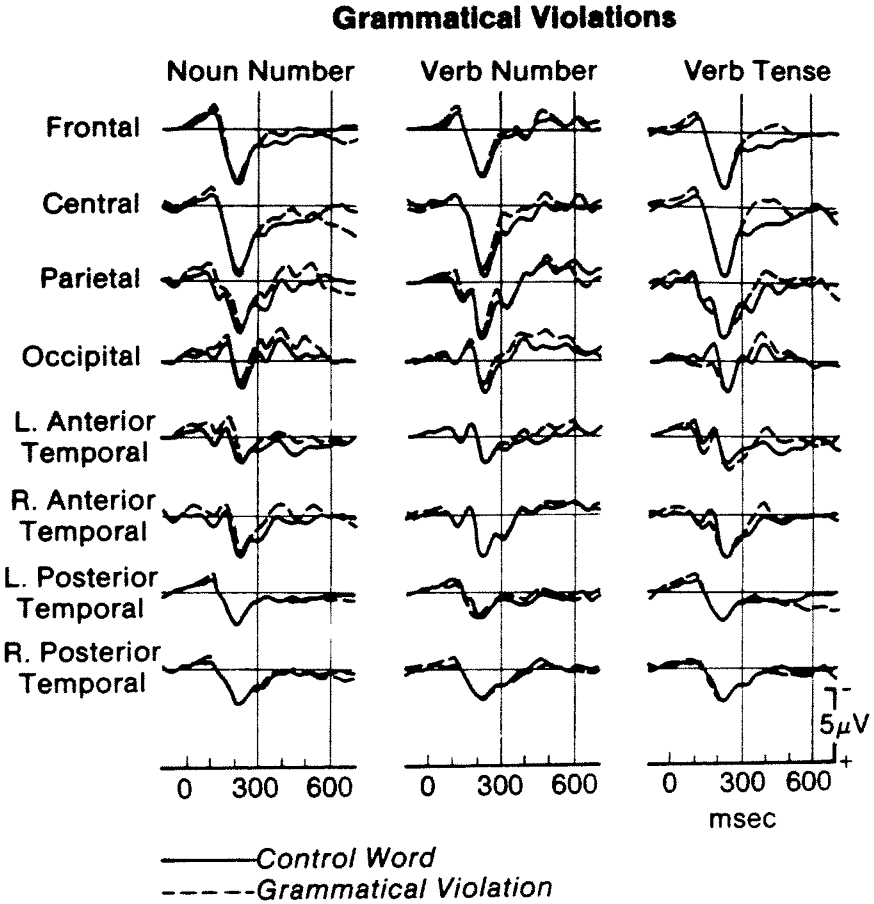

Figure 8. Grand average ERPs to each of the three types of grammatical errors. In each case, comparisons are made with ERPs elicited by semantically appropriate and grammatically correct control words occurring in comparable positions within the sentences. The proportion of function and content words in the control ERPs is equivalent to that in the grammatically deviant ERP with which it is compared. (From Kutas & Hillyard, 1983. Copyright 1983 by the Psychonomic Society. Reprinted by permission.)

ined this issue by systematically manipulating the expectedness of sentence terminations. None of the sentences in this experiment were anomalous. Rather, all of the sentence fragments were completed in a meaningful way, but varied in the predictability of their terminal words. The sentences were selected from a published set in which the degree of expectancy for alternative terminal words had been determined using a cloze procedure, i.e., by requiring a large group of subjects to fill in the missing terminal word (Bloom & Fischler, 1980). A word's cloze probability is defined in terms of the percentage of subjects using that word to complete a particular sentence.

The experimental design utilized words with different cloze probabilities (*hi, med, lo*) placed at the ends of sentences characterized by three levels of contextual constraint (*hi, med,* or *lo*). Highly constrained sentences were those that a large majority of subjects completed with a single given word (e.g., "He mailed the letter without a *stamp*."), while sentences of low constraint were rated as having a number of equally acceptable endings (e.g., "There was nothing wrong with the *car, food, knee, idea,* etc."). Figure 9 provides examples of each of the sentence types used.

Highly probable words at the ends of highly constrained sentences were followed by a broad late positivity (see Figure 9B). Low probability words, in contrast, elicited a large posteriorly distributed negative peak (N400). The N400 to low probability endings did not vary significantly over the three levels of contextual constraint (compare dotted and dashed tracings in Figure 9B). Whereas N400 amplitude did not vary significantly with contextual constraint, it proved to be quite sensitive to cloze probability. For example, comparisons of the ERPs to the high, medium, and low probability completions to sentences of medium contextual constraint revealed a gradient of N400 as a function of cloze probability: the less probable the ending, the larger the N400 (see Figure 9C). The relationship between cloze probability and N400 amplitude was evaluated statistically by product-moment correlations between the two measures. At posterior scalp sites these values ranged between 0.88 and 0.97.

Semantic Relatedness

These results, along with those of Fischler et al. (1983), suggest that the N400 component is little influenced by the overall plausibility of a sentence's propositional content. Rather, it seems that the appearance and amplitude of an N400 to a given word is determined by the degree to which the preceding sentence fragment has "prepared the way" for that word. "Priming" of words by appropriate sentence fragments is a phenomenon which has been demonstrated by shortened reaction times (Fischler & Bloom, 1979; Kleiman, 1980; Schuberth & Eimas, 1977; Schuberth, Spoehr, & Lane, 1981; Stanovich, 1981; Stanovich & West, 1983; Underwood & Bargh, 1982), or lowered detection thresholds (Morton, 1964; Tulving & Gold, 1963) in a variety of tasks. On the basis of these results, it has been proposed that reading a sentence fragment activates appropriate schemata along with a set of semantically related words (Foss, 1982; Thorndyke & Hayes-Roth, 1979).

If the N400 reflects some aspect of this semantic activation, its amplitude should vary according to whether or not a terminal word is semantically related to the expected terminal word for that sentence (Kleiman, 1980). And, indeed,

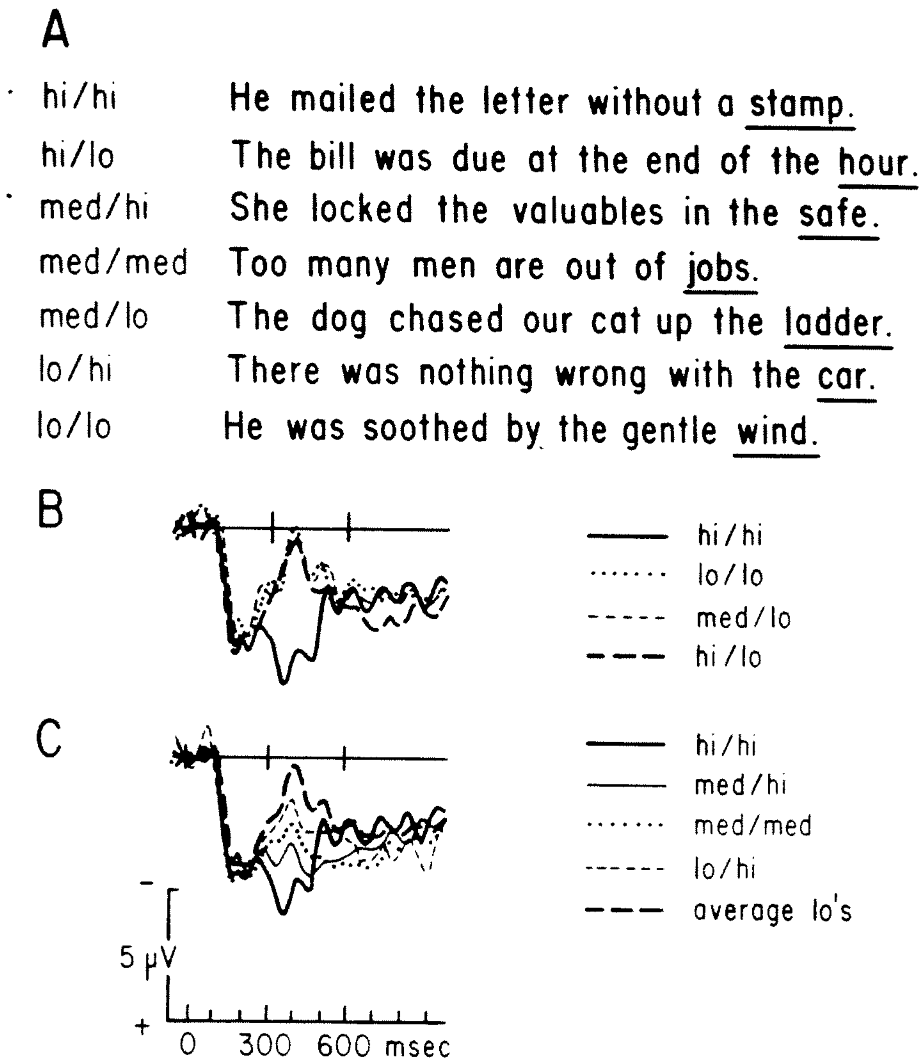

Figure 9. A. An example from each of seven classes of sentences that varied in degree of contextual constraint and in the cloze probability of the terminal word. On the left are shown the levels of contextual constraint/close probability for each class. The two dimensions are not wholly independent, since only the more highly constrained sentences have the possibility of being terminated by words of very high cloze probability. B. Grand average ERPs from the Pz electrode to low cloze probability words terminating sentences of high, medium, and low contextual constraint, together with the ERP to high cloze probability words terminating highly constrained sentences. C. Grand average ERPs to low, medium, and high cloze probability words terminating sentences of medium contextual constraint. (From Kutas & Hillyard, 1984b. Copyright 1984 by MacMillan Journals Limited. Reprinted by permission.)

N400 amplitude to low probability endings was smaller when the ending was semantically related to the expected ending than when it was not. For example, if the sentence fragment "George kept his dog on a . . ." was completed by the word "chain," which is related to the best completion, "leash," a smaller N400 resulted than if the completion were "diet."

The results of a follow-up study (Kutas, Lindamood, & Hillyard, 1984) showed that the effects of a semantic relationship between the expected word and the presented word were not restricted to meaningful sentences. Even a semantically anomalous word yielded a smaller N400 when it was related to the expected ending than when it was not (see Figure 10). These results indicate that while N400 amplitude fluctuates with expectancies set up by a sentence context, it is also responsive to associations between single lexical items, not all of which need be physically present. Such findings suggest that the N400 is not limited to sentence or prose contexts.

The N400 and Single-Word Contexts

A number of investigators have observed N400s in the ERPs to single words within a series of words. While there were suggestions of a late negativity in early experiments using words (Kutas, McCarthy, & Donchin, 1977; Posner, Klein, Summers, & Buggie, 1973), perhaps the first published data showing what appears to be a clear N400 is that of Sanquist et al. (1980). In separate experimental runs, they presented pairs of words (separated by 2000 ms) to be judged as "same" or "different" according to orthographic, phonemic, or semantic criteria. Although these investigators were concerned primarily with the relation of P300 amplitude to subsequent recognition, inspection of their waveforms reveals a large negative peak around 400 ms for the "different" words in the semantic task. They also obtained a smaller negativity for "different" words during the phonemic judgment task.

Harbin, Marsh, and Harvey (1984) intentionally recorded N400s in response to words within a non-sentential context in order to compare the ERPs of young and elderly subjects. Each trial consisted of a sequence of five words. A signal preceded the fifth word to indicate that it was a target. In one run, the first four words were identical and the fifth was either identical (15% of the trials) or different (85% of the trials). In the second condition, the first four words were drawn from the same semantic category (i.e., a list of cities, birds, parts of the body, etc.) and the fifth was from either the same category (15%) or a different one (85%). In each condition the subjects' task was to move a lever indicating a 'match' or a 'mismatch.'

The ERPs elicited by the four different types of fifth word stimuli are shown in Figure 11. Since a discussion of ERP changes with age is outside the scope of this review, only the data from young subjects are described. Each of the target words produced an N200–P300 complex. In both tasks, 'match' words produced

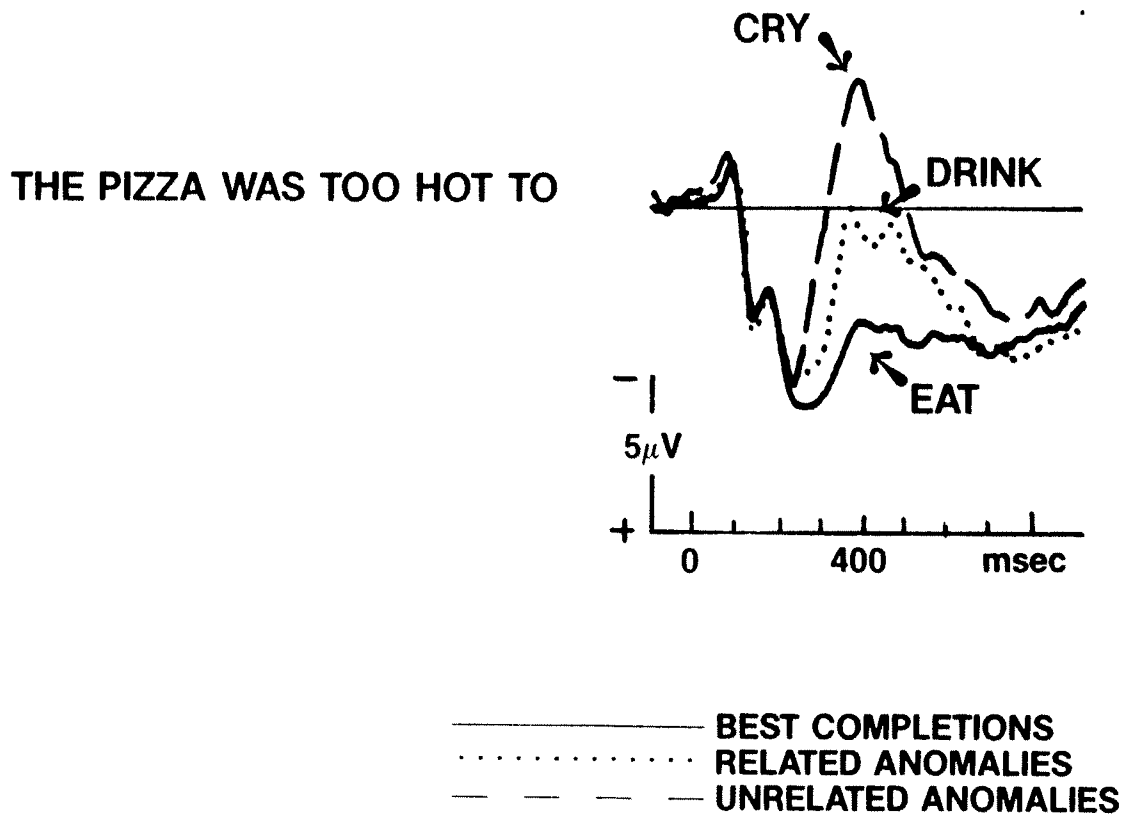

Figure 10. Grand average ERPs to the most expected (best) sentence completions, anomalous completions, and anomalous completions which were related to the most expected word. Site Pz. (Data from Kutas, Lindamood, & Hillyard, 1984.)

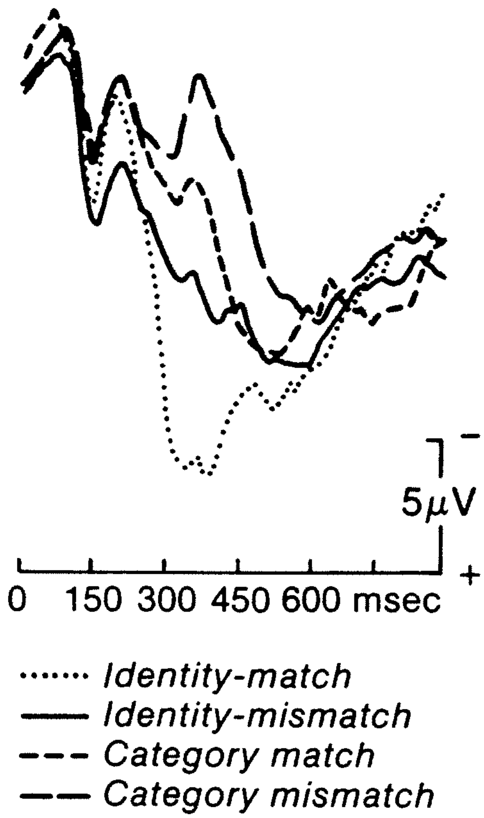

Figure 11. Grand average ERPs at site Cz from the Identity Match, Identity Mismatch, Category Match, and Category Mismatch in young subjects. (From Harbin, Marsh, & Harvey, 1984; Copyright 1984 by Elsevier Scientific Publishing Company. Reprinted by permission.)

a larger positivity than did 'mismatch' words, as would be expected from their lower probability of occurrence. The unequal probability of matches and mismatches, in addition to the response requirement, complicates the interpretation of these waveforms. The binary decision invoked by this task clearly elicits a large P300. It is difficult to tease apart the overlap of components associated with the decision and the motor response from those specific to semantic analysis. Nevertheless, it is possible to see components other than the P300 elicited by these words. All of the target waveforms contain an N200 component. Furthermore, in the three conditions wherein the fifth word was not identical to the first four, the N200 was followed by a second negative peak at about 375 ms, i.e., an N400. As would be expected from the N400's sensitivity to semantic deviation, this negativity was largest in the category mismatch condition (see also Boddy, 1981; Boddy & Weinberg, 1981).

It is of interest that an N400 was evoked in the identity mismatch condition even though the task could have been performed without access to word meaning. The possible interpretation of this finding touches on important issues which have been raised in the behavioral literature on word recognition and context effects. A brief summary of this literature will thus precede discussion of the potential relevance of ERP data to such psycholinguistic issues.

SEMANTIC PRIMING

The interaction of contextual factors with stimulus information in word recognition has been documented in numerous studies using various reaction time measures. The influence of a single word context has been studied extensively (for a review see Henderson, 1982). In a typical word-pair paradigm, subjects are presented with a stream of words upon which to perform some task, such as naming or lexical decision (i.e., deciding if a string of letters is a real word or not). On the whole, it has been found that both speed and accuracy are improved if the target word is preceded by a semantically related word as opposed to an unrelated word, a nonword, a "pseudoword" (pronounceable nonword), or some "neutral" stimulus such as a row of x's. This response facilitation for related words has been taken as empirical support for the idea that the entries in one's mental dictionary are clustered in some meaningful fashion. Although there is no agreement on the principles of organization within the mental lexicon or on how two words come to be associatively related, it is clear that reading or hearing one word affects the speed and quality of the processing of related words (Bolinger, 1965; Collins & Quillian, 1969; Johnson-Laird, Herrmann, & Chaffin, 1984; Katz & Fodor, 1963; Rips, Shoben, & Smith, 1973; Smith, Shoben, & Rips, 1974). Since accessing single words and integrating their meaning with preceding words are basic processes in language comprehension, the apparently simple phenomenon of 'semantic priming' has received a great deal of research attention.

Automatic and Attentional Processes in Semantic Priming

Among the more controversial issues in the semantic priming literature has been the relative contribution of 'automatic' and 'attentional' processes to producing the observed response facilitation. Few would argue that full understanding of a word's meaning can be a difficult cognitive act requiring substantial conscious attention. The case for an automatic component to word recognition is not as obvious. However, neither the task of naming nor the task of lexical decision, per se, require that subjects take note of the meaning of the first or 'prime' word. Nonetheless, we know by virtue of the semantic priming effect that not only has the meaning of the prime been accessed, but also that such access expedites the processing of related words. If this route from orthography to semantics cannot be diverted by experimental instruction, it must be obligatory and automatic. This is the view instantiated by the concept of "automatic spreading activation" within the mental lexicon (Collins & Loftus, 1975).

An influential theory which has attempted to reconcile the concept of an automatic process in word recognition with the attentionally-mediated process required to understand text was proposed by Posner and Snyder (1975a, 1975b). In their framework, automatic processes are unconscious, strategy-independent, and operate in parallel with other mental activities without producing interference. Conscious attentional processes serve to integrate the output of multiple and possibly antagonistic automatic processes; such conscious processes are distinguished by their limited capacity and slower time course. The limited-capacity attentional mechanism is able to afford greater efficiency of processing for events within the focus of attention only at the expense of less efficient processing for events outside the focus of attention. The activation of an automatic mechanism carries no such cost, because such mechanisms do not draw on a single limited pool of resources but rather operate independently.

A number of investigators have attempted to isolate the automatic component of semantic access within priming paradigms by manipulating subjects' expectancies for related and unrelated items (De Groot, 1984; Den Heyer, et al. 1983; Fischler, 1977; Tweedy & Lapinski, 1981; Tweedy, Lapinski, & Schvaneveldt, 1977). Such experiments have relied on the working assumption that if RT facilitation for related words cannot be accounted for by conscious expectancies (i.e., attention), than it must result from an automatic process. Subjects' expectancies or predictions for related pairs are presumably eliminated by reducing the number of related word pairs in an experimental session. The remaining RT facilitation for related pairs is then assumed to reflect automatic processes. Thus, although Tweedy, Lapinski, and Schvaneveldt (1977) found greater semantic priming with a high than with a low proportion of related pairs, they attributed the residual priming effects to an automatic process. Similarly, Fischler (1977) argued in favor of automatic activation based on his finding that even the first related word following a series of unrelated or nonword pairs showed an RT facilitation.

Both Tweedy et al. (1977) and Fischler (1977) manipulated subjects' expectancies indirectly, relying on the assumption that subjects were not only aware of the proportions of related and unrelated items, but that they also altered their processing strategies accordingly. Subjects were presumed to suppress any expectancy for semantic relationships when the number of related items was low, because the most efficient strategy was to expect unrelated pairings.

Neely (1977) controlled subjects' expectancies in a more direct manner via experimental instructions. Rather than varying the proportion of related items, Neely manipulated the nature of the relationship between the prime and target, and the interval between them. Subjects were told that target words representing parts of the body would usually follow the prime word "building" (e.g., "building-leg") while targets referring to parts of buildings would usually follow the prime "body" (e.g., "body-door"). Via these nonsemantically-related yet predictable pairs, Neely could assess the effect of conscious expectancies in isolation of automatic processes. Likewise, by occasionally presenting unexpected but semantically related prime-target pairs (e.g., body-leg), he could examine automatic processes independent of conscious expectancy. The inter-stimulus interval was manipulated to test Posner and Snyder's proposition that short intervals allow only automatic activation, whereas longer intervals allow both automatic and conscious processes to be called into play.

Neely's results showed that the responses to targets following semantically related primes were facilitated relative to those following a neutral stimulus (a string of x's) at short intervals, even though such pairings occurred infrequently and in direct contradiction to the expectancies set up by the instructions. The RTs to these semantically related pairings were not facilitated at longer intervals. In addition, Neely found that target RTs for predictable but unrelated pairs were shortened (relative to those following the neutral prime) only at long intervals. To date, these results have provided the strongest support for the idea that priming consists of two separable sub-processes, a fast-acting component based in word associations learned as a part of one's language, and a slower component reflecting one's conscious expectancies.

While a particularly compelling demonstration of the automatic nature of semantic priming would be the persistence of the effect in the complete absence of consicous processing, these data are equivocal. Marcel (1983a, 1983b; see also Evett & Humphreys, 1981) has reported that semantic priming effects can be obtained even when the prime word has been rendered inaccessible to consciousness by visual masking. However, most reports of response facilitation following "unconscious" primes have been criticized for inadequate threshold determinations or failure to take into account subjects' hesitancy to report a barely detectable word (Holender, 1986; Merikle, 1982). Despite the numerous studies which have been directed at the role of automatic spreading activation in word recognition, the issue remains unresolved.

ERP'S AND SEMANTIC PRIMING

The Pros and Cons of the ERP Technique

The foregoing review should have made apparent the difficulties of measuring a process that is presumably both automatic and unconscious. While a number of ingenious techniques have been applied with some success, such procedures invariably put the experimenter in a quandary—how to obtain behavioral responses to the stimuli of interest without inducing special processing strategies which would not occur in normal reading. Just as perplexing has been the problem of how to measure a quick mental process with a relatively slow verbal or manual response. Although a fluent reader can fixate and comprehend several words within 200 ms (Rayner, 1983), reaction times in a priming paradigm are seldom less than 500 ms. Much effort within cognitive psychology has, in fact, been concerned with delineating the processes which might account for this time difference.

It is just such a concern for the intervening mental process that underlies the controversy within the behavioral literature about the relative merits of the lexical decision and naming tasks. Recently, it has been argued that lexical decision times cannot provide a good estimate of the effect of semantic priming on the speed of lexical access because part of the RT reflects the time devoted to 'postlexical' decision processes (Balota & Chumbley, 1984; Seidenberg, Waters, Sanders, & Langer, 1984; West & Stanovich, 1982). It has proven difficult to analyze the RT into its subcomponents by means of behavioral measures alone (Coles, Gratton, Bashore, Eriksen, & Donchin, 1985; Duncan-Johnson & Donchin, 1982).

Accordingly, the need for convergent measures of mental processes has led a few researchers to apply the ERP technique to some of the issues in word recognition. Since ERP measures are not contingent upon overt responses and can be obtained to stimuli both within and outside the focus of attention, they should, in theory, increase our chances of catching unconscious processes in a slightly more natural setting than has usually been employed. ERPs also make it possible to compare measures to the same physical stimuli presented under varying task conditions, in order to determine which brain processes are obligatory responses to the stimuli and which are task-dependent.

In contrast to most behavioral measures, which are discrete and somewhat delayed relative to the process under investigation, ERPs provide an immediate and continuous record of brain activity following the presentation of a stimulus. Unfortunately, at present, this strength of the ERP is also a drawback insofar as multiple and simultaneous mental processes (see McClelland, 1979) are reflected in overlapping ERP components. At present, there are only a limited number of analytic techniques for separating overlapping components and these are controversial (Hunt, 1985; Wood & McCarthy, 1984); yet the ERP waveform may provide the clearest available record of concurrent cognitive processes. Although the application of ERPs to language-related issues is in its infancy, it is clear that the technique will provide a powerful source of convergent evidence in the investigation of psycholinguistic questions.

The potential utility of the ERP technique has not been exploited fully. In fact, most ERP studies of semantic priming have remained very close to the paradigms developed in previous behavioral research. The naming task used in semantic priming paradigms has, thus far, proved incompatible with ERP recording because of the contamination by several speech-related artifacts (e.g., electromyogram, glossokinetic potential, respiratory potential, etc; for reviews see Grozinger, Kornhuber, Kriebel, Szirtes, & Westphal, 1980; Picton & Stuss, 1984). No one has yet investigated semantic priming in masking paradigms using ERP measures. However, several investigators have recorded ERPs during the lexical decision task. Although the interpretation of the ERPs recorded during the lexical decision task is somewhat problematic because of the overlap of decision-related components with "priming-related" components, such studies have utilized various subtraction procedures to yield evidence on the role of semantic priming in word processing that converges nicely with behavioral data.

ERPs in the Lexical Decision Task

Bentin, McCarthy, and Wood (1985) were the first to demonstrate the feasibility of using ERPs to study priming in a lexical decision paradigm (LDT). Their subjects were presented with a steady stream of intermixed words and pseudowords and instructed to press one button for words and another for pseudowords. For the purposes of this review, we will consider only the responses to word stimuli. Eighty of these were preceded by semantically related words, 160 were preceded by unrelated words or pseudowords. Reaction times followed the usual pattern for this task: words that had been primed by a preceding semantic associate were judged to be real words more quickly than were unprimed words. Figure 12 shows that the ERPs to words were similar to those of Harbin et al. (1984) in that each stimulus type elicited an N200–P300 complex. In addition, the ERPs to both primed and unprimed words contained a negative peak around 400 ms. This N400 was significantly larger for words which had not been preceded by a related word.

ERP Investigations of the Automatic and Attentional Aspects of Priming

The Bentin et al. (1985) study was a rather straightforward application of ERPs to the semantic priming/lexical decision paradigm. Their results showed not only that interpretable ERP data could be collected in an LDT paradigm, but also that such findings were consistent with the proposed relationship between the N400 component and semantic priming. Other ERP investigations of semantic priming have included manipulations of some of the variables commonly thought to affect the balance between automatic and attentional processes: the temporal interval between prime and target (i.e., stimulus onset asynchrony—SOA), the task assigned to the subject, and the proportion of related to unrelated word pairs.

The Influence of SOA

Boddy (1986) compared the effect of short (200 ms) and long (1000 ms) SOAs on semantic priming in a lexical decision task. His data were generally in line

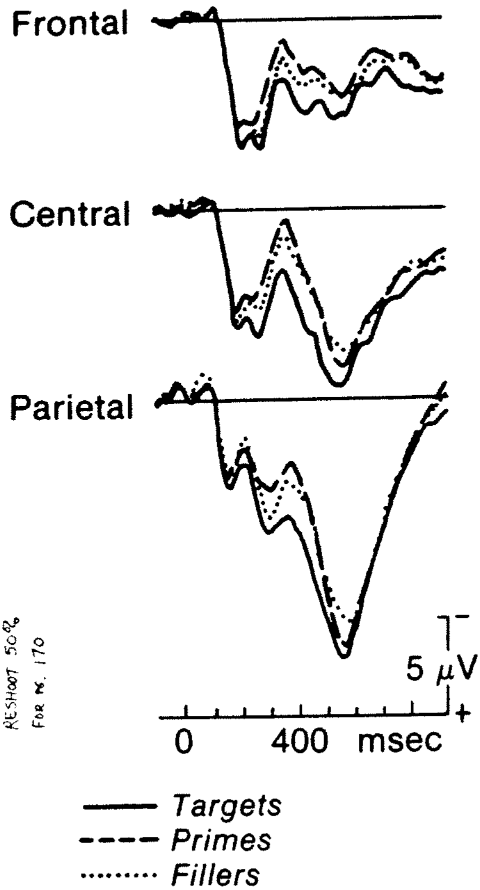

Figure 12. Grand average ERPs in the lexical decision task. 'Primes' and 'targets' were the first and second words of semantically related pairs, respectively. 'Fillers' were neither preceded nor followed by semantic associates. (From Bentin, McCarthy, & Wood, 1985. Copyright 1985 by Elsevier Scientific Publishing Company. Reprinted by permission.)

with previous reports: relative to the prestimulus baseline, the ERPs to primed words remained positive, while unprimed words elicited a large N400. In addition, Boddy concluded that the ERP differences between primed and unprimed words were quite similar at the short and long SOAs. Boddy's interpretation that ERP indices of semantic priming were unaffected by SOA is, however, weakened by his analytic procedures.

Because the prime and target ERPs elicited at short SOAs overlapped, Boddy subtracted the ERP to the prime at the long SOA from the compound prime-target ERP obtained during the short SOA. This subtraction procedure is based on the assumption that brain electrical activity associated with processing of the prime is unaffected by the subsequent target; that is, that the cognitive processes and associated waveforms are additive rather than interactive. The validity of this assumption can be questioned given that anticipatory potentials (e.g., Contingent Negative Variation—CNV) have different timecourses, morphologies, and resolutions depending on foreperiod length (as between the prime and target; see Deecke, Neisser, & Ziller, 1980; Rohrbaugh & Gaillard, 1983). The influence of SOA on the later endogenous components of the ERP is largely unknown. Such factors make the subtraction procedure questionable. Given the impact of varying SOAs on behavioral measures of semantic priming, and the critical role that this factor plays in theories of semantic priming, additional information on the effect of temporal variables on the N400 and P300 elicited during the LDT is desirable.

The Influence of Task Demands

In separate studies, Kutas (1981, 1985a) has investigated the influence of different task requirements on the ERP response to primed and unprimed words. This work was originally motivated by the need to develop an ERP paradigm suitable for isolating the N400 response in the word pair paradigm, yet the results bear on the automatic/attentional distinction. Although it is probably essential to assign subjects some task in a word pair paradigm in order to assure their continued cooperation, one would like to eliminate the P300 component elicited by the lexical decision task. Because both the N400 and P300 components tend to occur within the same time frame (i.e., 300 to 600 ms post-stimulus), it is not only difficult to tease apart their relative contributions to the resultant waveforms recorded at the scalp, but also difficult to assess the impact of different experimental manipulations on the parameters of each. Thus, the morphology and scalp distribution of the N400 as it relates to semantic priming can be more easily visualized and directly measured in the absence of an overlapping P300 component. The absence of decision-related componentry also allows a more direct comparison between the ERP correlates to priming by a sentence context—in which there is usually no immediate response requirement—and priming by a single word context.

One means of achieving this goal has been via a letter search task in which a single trial consisted of two words (SOA = 700 ms) and a single letter in sequence. The measurement of interest in Kutas' study was the relative change in the amplitude of the N400 elicited by the second word in a trial as a function of its semantic relationship to the first word. The subject's task, however, did not draw attention to these varying semantic associations (75% related, 25% unrelated); rather, subjects were asked to indicate whether the letter subsequent to the word pair (by at least 1 s) was or was not present in either or both of the words. In this way, the subject's task decision and the associated P300 component were delayed well beyond the ERP to the "target" word eliciting the N400 wave.

The ERPs to all "target" or second words contained an N400 component regardless of their semantic association to the preceding "prime" words (see Figure 13). The N400s to the unprimed words were significantly larger in amplitude than those to the primed words. The size of the N400 difference between semantically related and unrelated word pairs was appreciably smaller than the difference between anomalies (or low cloze probability endings) and best completions of sentences. It is possible that the small primed/unprimed difference in this word-pair experiment was due to the insufficient engagement of semantic

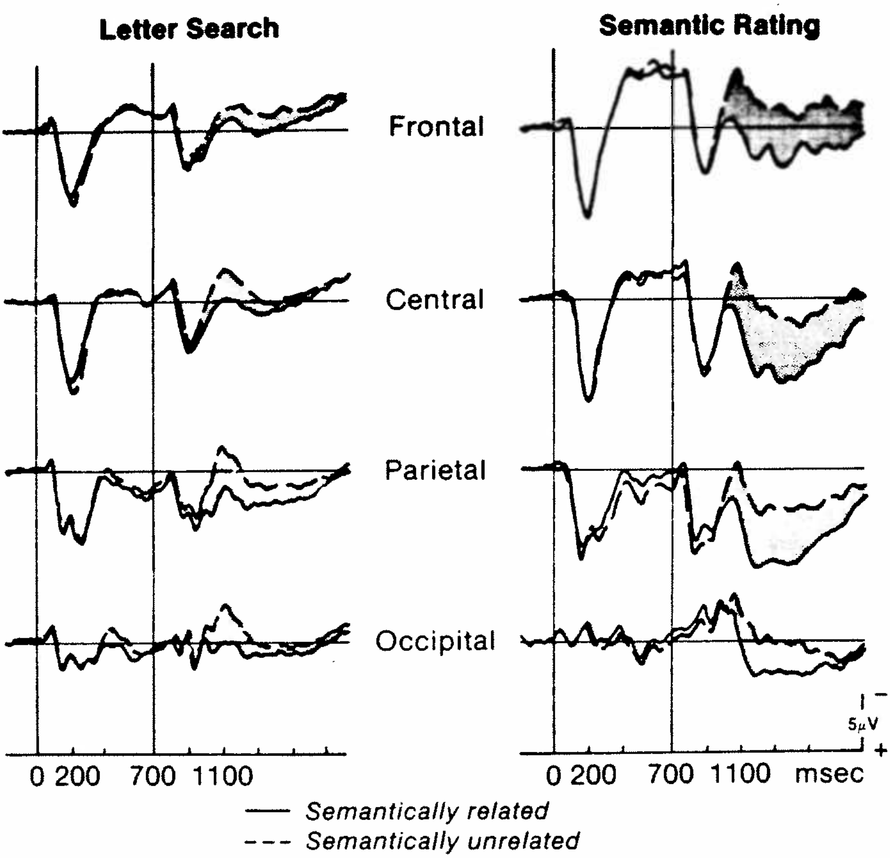

Figure 13. Left column: grand average ERPs for the letter search task, second words of related and unrelated pairs. (Data from Kutas, 1985a.) Right column: Grand average ERPs for the semantic rating task, second words of related and unrelated pairs. (Kutas, see Note 2.)

processes, given that the letter search could be performed without semantic analysis of the target words (cf. Bentin, McCarthy, & Wood, 1985). On the one hand, it may have been that subjects accessed word meanings on only a subset of the trials. On the other hand, all words may have been processed to a "deep" (i.e., semantic) level automatically. In this latter case, the small amplitude of the N400 effect may have reflected only this automatic component of semantic priming.

In an experiment which bears on this discussion indirectly (Kutas, 1981), subjects were assigned the task of rating (5-point scale) the strength of the semantic association between two sequentially presented words (SOA = 700 ms). The stimuli were similar to those used in the word pair letter search task: related and unrelated pairs were of equal probability. Figure 13 (right column) shows the ERPs elicited by related and unrelated second words in this study.

The effect of drawing attention to the relationship between the first (prime) and second (target) words is evident in the large frontal negativity (CNV) that develops during the interval between the two words (cf. Holcomb, 1986). As in the letter search task, both primed and unprimed targets were associated with N400-like waves, albeit larger following unprimed words. The N400s to unprimed words in this semantic rating task were relatively similar to those observed in association with these same stimuli in the letter search task. However, the ERPs associated with the primed words and, as a consequence, the difference between the ERPs to primed and unprimed words were quite different across the two tasks. The ERPs to primed words were characterized by substantially more late positivity than in the letter search task. This positivity may in part reflect the brain activity associated with the rating decision, which was probably not delayed even though the motor response was. Note however, that both primed and unprimed words required a decision and were equiprobable in occurrence, so that both types of words should have elicited a similar late positivity during the rating task. Nonetheless, the N400 difference waves were larger in this experiment than in the letter search task.

It should be noted that even in the semantic rating task, the ERP difference wave between primed and unprimed words is somewhat smaller than the difference between anomalous (or low cloze probability) and best completions of sentences. This amplitude differential between the N400 difference waves generated within sentence and word-pair paradigms may be partially due to the fact that a sentence fragment generally provides a stronger, more restrictive context than does a single word. Highly probable sentence completions are associated with greater positivity (or less negativity) than are semantically related items in a word pair task; hence, the larger N400 effect (i.e., difference wave) following priming by sentence fragments than by single words. The size of the N400 priming effect due to a single word context was more like that resulting from a sentence fragment of low to medium contextual constraint than that due to sentence frames of high constraint (see also Kutas, 1985a). This is consistent with the observation of small positivities or—in some cases—small negativities following meaningful, but low probability, sentence completions. (Kutas & Hillyard, 1984b; see Figure 9). A comparison of the N400s elicited by target words occurring in weak (e.g., category) and strong (e.g., antonymic) pair relations also would provide valuable information on this proposition. If our reasoning is valid, antonym pairs should yield larger N400 effects than pairs comprised of category members when each pair is contrasted with the response to an incongruent or unrelated target.

A conclusive comparison of the ERPs elicited in priming paradigms using sentences and those using words awaits further research. However, the amplitude difference between the N400s elicited by different tasks within word-pair paradigms indicates that the size of the N400 effect can be influenced by attentional manipulations which direct subjects' processing strategies towards semantic analyses. Kutas' data (1981, 1985a) also suggest that directing subjects' attention to word meanings has more of an impact on the response to primed than unprimed words.

The Influence of Varying the Proportion of Related Word Pairs

Holcomb (1986) has examined the effects of attentional vs automatic modes of word processing by varying the proportion of related word pairs in separate sessions of a lexical decision task. In the 'automatic session,' one-eighth of the target letter strings were semantically related to the preceding prime event; in the 'attentional session,' half of the targets were related. Subjects were required to respond to only the second (target) letter string of each pair. In the automatic session, subjects were instructed that the first (prime) stimulus served only as a warning signal for the target stimulus; in the attentional session, they were encouraged to utilize the probability of a semantic relationship between prime and target to speed their response times.

The behavioral results were consistent with the Posner-Snyder theory. Relative to the automatic session, the attentional session yielded faster RTs and fewer errors on related trials, but slower RTs and more errors on the unrelated trials. This pattern of results presumably reflects the benefit derived from using the prime word to predict the target word on some proportion of related trials, and the cost of an incorrect prediction on the unrelated trials.

Comparison of the ERPs elicited in the two sessions requires care because, once again, a P300 and N400 occur in the same latency band and the experimental manipulations may have affected one or both components. Related pairs were a low probability occurrence in the automatic session, while in the attentional session related and unrelated pairs were equiprobable. We might then have expected the overall ERP differences in the automatic session to be inflated by the occurrence of a P300 to the low probability related pairs. However, the potentially confounding influence of the differential probabilities on the P300 predicts results opposite to those obtained since Holcomb reported a *smaller* related-unrelated difference in the automatic session. We tend to believe that the enhanced relatedness effect in the attentional session was due to subjects' enhanced processing of prime-target relationships, whether this was due to the subjects' perceptions that many of the words were related, the experimenter's instructions, or both.

Evidence that the probability of congruity or incongruity, in and of itself, is not a crucial factor in determining N400 amplitude can be adduced from sentence experiments. In each of the sentence N400 paradigms to date, all of the sentences have made sense up until a single word that differentiated congruous and incongruous sentences. In such situations, subjects seem likely to maintain, by default, the expectation that sentences will continue to make sense. In the experiments of Kutas and Hillyard, the instructional set "to read with care in order to answer questions later" also would have acted to encourage an attentional mode of processing. In this series of experiments, increasing the proportion of incongruous ending form 25 to 50% has had no noticable effect on the amplitude or latency of the N400 (Kutas, Lindamood, & Hillyard, 1984). In contrast, the subjects' level of attention and degree of semantic analysis may prove to be important factors underlying N400 amplitude.

Semantic Priming and Mode of Processing

We have seen in both Kutas' and Holcomb's studies that a task or an instructional set which encourages semantic processing of the first (prime) word of a pair enhances the N400 to unrelated second words. Both experimenters also observed N400 components under conditions which did not require semantic analysis of the prime. However, both Kutas' letter search and Holcomb's automatic instructions left undefined the cognitive processes which subjects could have *chosen* to engage during the interval between the first and second word of a pair.

Recent behavioral work has shown that cognitive set may be a crucial variable in determining the magnitude of semantic priming. In a lexical decision paradigm, Smith, Theodor, and Franklin (1983) assigned separate groups of subjects different tasks to be performed on prime words. 'Visual analysis' required deciding whether or not the prime had a star in front of it; 'letter search' involved comparing each letter of the prime with a string of letters just above it; 'phonemic analysis' entailed a syllable count; 'read' consisted of silent reading; and 'semantic analysis' required a decision as to whether the prime word represented a living or nonliving object. When the prime was analyzed in a "shallow" way, namely, visual analysis or letter search, lexical decision times were unaffected by the semantic association between the prime and target words. Phonemic analysis or silent reading of the prime resulted in the more typical reaction time facilitation for related versus unrelated targets. Semantic analysis of the prime led to the greatest reaction time facilitation for related targets.

The ERP studies of Kutas (1981, 1985a) and Holcomb (1986) and the reaction time study of Smith et al. (1983) all lead to the same conclusion: there is a sizeable attentional component to the semantic priming effect which is readily altered by instruction and task. This is perhaps no surprise; much research has been devoted to a search for the more elusive, hypothetical, automatic component of semantic priming. Smith's systematic manipulation of the type of processing devoted to the prime highlights an important point, however; "semantic priming," whether measured by reaction time or ERP techniques, is typically defined by the response to the second word of a pair. It may be that facilitated processing of semantically related second words is an automatic consequence of exposure to a prime word, but only if the subject is "in" a semantic processing mode. The observation that semantic priming effects occur when no specific analysis is assigned to the prime, as in most previous behavioral and ERP research, may imply that semantic analysis is the default mode of processing when dealing with linguistic stimuli, rather than a truly automatic process that cannot be suppressed if the exigencies of the situation so require.

Smith et al. (1983) concluded that a "deep" (i.e., semantic) level of processing led to semantic priming while "shallower" (i.e., visual or orthographic) levels did not. Note, however, that these results can be restated to say that it is the equivalence between the level at which a word is analyzed and the level at which priming is sought, rather than depth of processing, that is important: thus, semantic processing leads to semantic priming while other types of processing do not. Thus, it is possible that a letter search of the prime (e.g., orthographic analysis) would have resulted in faster lexical decision times for orthographically similar targets, just as the semantic task led to faster RTs for semantically similar targets. In fact, a number of LDT studies have demonstrated that word similarity at the orthographic (e.g., a word's appearance and spelling) and phonemic (e.g., a word's sound) levels influences reaction time (Hillinger, 1980; Meyer, Schvaneveldt, & Ruddy, 1974; Shulman, Hornak, & Sanders, 1978). The question of whether orthographic, phonemic, and semantic priming are distinct and separable processes which may interact during normal reading remains unanswered, with the proposed options being highly controversial.

THE N400 AND NONSEMANTIC PRIMING

It is clear that neither orthographic nor phonemic processes are *necessary* for the elicitation of the N400. The translation from an orthographic representation to a semantic or phonemic representation is bypassed in the comprehension of speech; nonetheless, auditorily presented semantic anomalies elicit N400s (Holcomb, 1985; McCallum et al., 1984). Similarly, N400s following semantic anomalies have been observed in the congenitally deaf, for whom language arrives via visuo-manual, gestural rather than phonological codes (Kutas, Neville, & Holcomb, 1987; Neville, 1985).

ERPs Associated with Phonemic and Orthographic Processing

The results of a study by Sanquist et al. (1980) suggest that orthographic and phonemic "mismatches" may elicit N400s if the subjects' task requires the detection of such mismatches. These investigators compared the ERPs elicited by pairs of words (separated by two seconds) which were judged as "same" or "different" according to orthographic, phonemic, and semantic criteria in separate runs. A large prolonged negativity (N400) was obtained for the second words considered to be nonsynonymous. A smaller and shorter duration negativity peaking at about 350 ms was obtained for nonrhyming words and a similar, although statistically nonsignificant, negative peak appeared following words which deviated in case (upper versus lower) from that of the preceding word.

Sanquist et al. did not define these negativities as N400s, but conclusive identification of these ERP component would prove of great interest in the psychophysiological study of linguistic processes. The appearance of the same ERP component (in this case the N400) across tasks would implicate activity in a common pool of neurons. Each individual task may also involve additional and distinctive neural activity, but the identification of a neurophysiological commonality between orthographic, phonemic, and semantic processes would provide invaluable data for analyzing the sequence of operations in transcribing a letter string into a meaningful representation.

No ERP study has examined semantic, orthographic, and phonological analyses simultaneously; however, several have focused on the interaction between the orthographic and phonological levels of word recognition. For example, Polich, McCarthy, Wang, and Donchin (1983) examined the independence of the phonological and orthographic levels via RT and ERP measures obtained while subjects matched pairs of visually presented words on the basis of their visual or rhyming characteristics. The pairs included words which either rhymed and looked alike (R+, 0+), rhymed but did not look alike (R+, 0−), looked alike but did not rhyme (R−, 0+), or did not look alike and did not rhyme (R−, 0−). Although the authors restricted their analyses and discussions to variations in P300 latency, inspection of their ERP waveforms indicates that the P300s were preceded by a large negativity peaking around 400 ms (see Figure 14). The amplitude of this negativity seemed to vary systematically with the experimental variables.

When subjects were to decide whether two words rhymed, all second word ERPs with the exception of those to R+0+ words were characterized by a negativity at about 400 ms after the second word. Not only was this N400 larger following nonrhyming than rhyming pairs regardless of their orthographic sim-

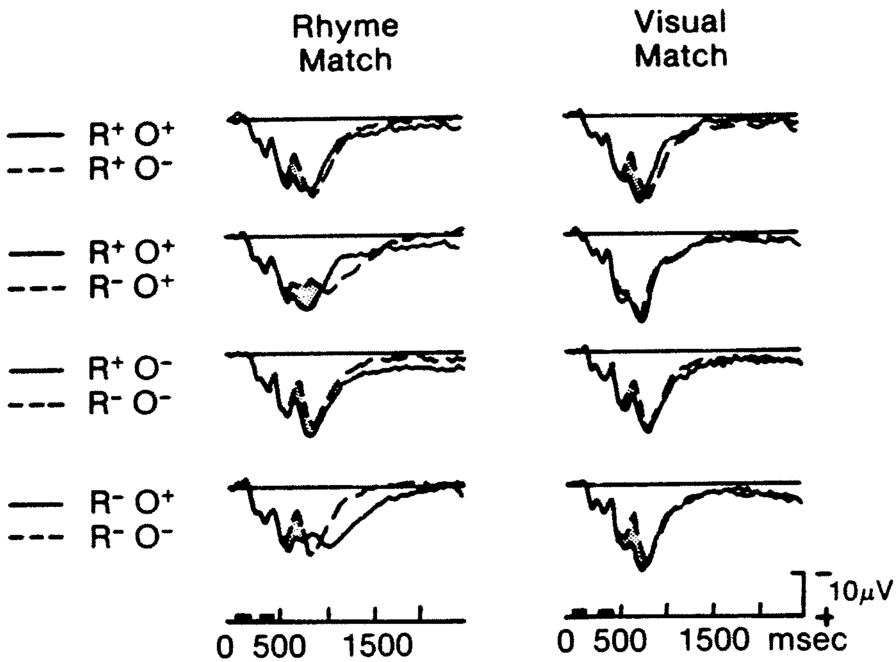

Figure 14. Grand average ERPs for word pairs in the rhyme and visual match tasks, site Pz. Onset of the first word was at 0 ms, second word at 250 ms. R + 0 + pairs rhymed and were orthographically similar; R + 0 − pairs rhymed but were orthographically dissimilar; R − 0 + pairs did not rhyme but were orthographically similar; R − 0 − pairs did not rhyme and were orthographically dissimilar. (From Polich, McCarthy, Wang, & Donchin, 1983. Copyright 1983 by Elsevier Science Publishers B.V. (North Holland). Reprinted by permission.)

ilarity, but it was also larger following words which did not look alike relative to those which did, regardless of their phonological similarity. Likewise, when subjects were to decide whether two words were visually similar or not, orthographically dissimilar words were associated with larger N400s than were orthographically similar ones. This effect was independent of the words' phonemic similarity; the ERPs to rhyming and nonrhyming pairs were indistinguishable; neither elicited an N400 component.

These data are consistent with our previous observation that an N400-like component can be elicited under conditions which place no explicit emphasis on semantic level processing of words. Moreover, they indicate that engagement of phonological and orthographic processes may influence the amplitude of this N400 component. More importantly, these ERP data point to an asymmetry in the influence of phonological and orthographic information during rhyme and visual matching conditions: orthographic dissimilarity resulted in N400s regardless of the task, while phonological dissimilarity elicited N400s only when the phonology of the word was task relevant (i.e., during rhyming tasks). These data are consistent with previous reports of subjects' apparent inability to ignore orthographic information during a rhyme-monitoring task (Seidenberg & Tanenhaus, 1979).

Rugg (1984a) also has investigated the ERPs elicited during the sequential matching of pairs of words on either phonological or physical criteria. Rugg's rhyming stimuli most closely resembled the R+O− pairs of the Polich et al. study; that is, words which rhymed but did not look alike. In two such experiments, Rugg found that the ERPs to nonrhyming words under rhyme matching instructions elicited a right hemisphere preponderant negative component between 300 and 600 ms post-stimulus (N450). No such difference in the 300 to 600 ms region was observed when subjects' match/mismatch decisions were based on the case (upper versus lower) in which the words were presented. In a follow-up study, Rugg (1984a) reported that the rhyme/nonrhyme differences were independent of the lexical nature of the stimuli; N400s followed phonological mismatches whether they occurred between two words or between a word and an orthographically legal pseudoword. Rugg (1985) has also found that the right hemisphere preponderance of the N450 following nonrhyming words was unaffected by subject handedness; similar results were obtained for right handers with no left-handed relatives and left-handers with a family history of left-handedness.

Insofar as the N400/N450 components to phonological mismatches recorded by Polich and Rugg can be considered equivalent to the N400 following semantically unexpected words, several tentative conclusions can be reached. Differential processing at the semantic, phonological, or orthographic levels appears to be sufficient to alter N400 amplitude. Phonological processing (or priming) of visually presented words appears to be optional rather than obligatory; nonrhyming words do not always yield larger N400s than do rhyming words. Although the data for the obligatory nature of semantic and orthographic priming are scant, the ERP evidence to data is consistent with an automatic and attentional component to each (for related behavioral evidence see Donnenwerth-Nolan, Tanenhaus, & Seidenberg, 1981). Future ERP studies, in conjunction with the behavioral evidence from traditional cognitive psychology (e.g., Baron, 1973; Davelaar, Coltheart, Besner, & Johasson, 1978; Hawkins, Reicher, Rogers, & Peterson, 1976; Kleiman, 1975; Rubenstein, Lewis, & Rubenstein, 1971; Spoehr, 1978), will help delineate the automatic and optional routes by which word meaning can be accessed.

CONCLUSIONS

In this review, we have described the experimental conditions which yield an N400 component and we have presented our views about the cognitive processes manifested by this component. Most of the experiments conducted as of this date have been devoted to validating the ERP as a measure of linguistic processing. These studies have indicated that the N400 component of the ERP is closely linked to semantic priming, and perhaps to priming at the phonemic and orthographic levels as well. More research remains to be done before we can be totally confident about our conclusions concerning the particular aspects of linguistic processing manifested by this ERP component.

The mechanisms whereby a word or sentence can prime another word are of some interest in and of themselves because they serve to combine individual words into a coherent message. The ERP will serve as a useful measure in charting the time course of this mechanism, as well as in clarifying the interrelationships among the various types of priming. Moreover, the phenomenon of reaction time priming has been utilized as a tool in the investigation of other issues, such as the processing of ambiguous words, the comprehension of metaphor, and phonemic recoding during reading (Gildea & Glucksberg, 1983; Hillinger, 1980; Simpson, 1984). ERP measures of priming are currently being applied to such issues in the expectation that a new and complementary source of data may assist in resolving these issues (Fainsilber, Miller, & Ortony, 1984; Polich, McCarthy, Wang, & Donchin, 1984; Van Petten & Kutas, 1987). Future reviews of ERPs and language will, no doubt, be able to start with the assumption that electrophysiological measures manifest language processes, and to build on our present groundwork to detail the contributions of ERPs to the resolution of specific questions in language research.

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